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***Research Article***

# APPLICATION DEVELOPMENT OF SOIL MOISTURE DEFICIT INDEX (SMDI) FOR AGRICULTURE DROUGHT MONITORING (CASE STUDY: ZARGHAN REGION, FARS PROVINCE IN IRAN)

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## ABSTRACT
Soil moisture is one of the most important parameters in soil-water moisture balance and from an agricultural perspective, when the soil moisture is faced with short coming, the agricultural drought has been occurred. Some indices are commonly used to investigate drought types which are based on meteorological data, especially rainfall, due to its simplicity and availability of information. But in terms of agriculture, drought often depends on soil moisture and considers soil as the main medium to meet the water requirements. Therefore, soil moisture parameters should be considered for agricultural drought monitoring as well. Soil Moisture Deficit Index (SMDI) is one of the most important indicators that have been recommended for monitoring agricultural drought and soil moisture is its required data. Because of the lack of direct measurements of soil moisture in weather stations and lack of quantitative data, this index is of low efficiency and has been used on a limited basis. In this study, a model was used based on the relationship between soil, water and plants which has recently been presented by FAO (AquaCrop model) that is a simulation model. Using daily meteorological data and soil characteristics of Zarghan Region, the soil moisture were simulated in a 20-year period (1992 to 2012). Then, based on the obtained results, the SMDI index was calculated and presented for monitoring agricultural drought. Also, the results of this index were compared with the common drought indices and they were analyzed based on the data of rainfall and potential evapotranspiration. All indicators show that from 2005 onwards, the region has had no wet year and suffered from drought and its intensity has been steadily rising. In 2010 and 2011, the most severe droughts occurred that all three criteria in this case showed similar results. In following, for a closer look at the results, relationships between indicators of drought, rainfall and evapotranspiration were investigated. The SMDI index shows the lowest coefficient of determination with drought and SPI and RDI indices. Generally the reason of the low value of SMDI's coefficient of determination is the difference in the nature of the index. SPI and RDI indices are calculated based on rainfall amounts, therefore, their correlation with rainfall is suitable.

***Keywords**: Drought, Soil Moisture, SMDI, Zarghan*

## INTRODUCTION
Soil moisture is the most important component for the sustainable production of agricultural products. By reducing the amount of rainfall and change in atmospheric phenomena such as precipitation reduce, temperature increase, the occurrence of strong winds, reduce in the relative humidity, increase in radiation hours etc., the meteorological drought begins. Then by increase in evapotranspiration and soil moisture decline, due to the imposed stress on agricultural plants and horticultural crops, the drought occurs.
Agriculture is often the first sector to be affected by the onset of drought due to dependence on water resources and soil moisture reserves during various stages of crop growth (Narasimhan and Srinivasan, 2005). From the agricultural perspective, drought more associated with soil moisture and considers soil as the main environment to meet water needs. From the agricultural perspective, this phenomenon leads to reduce in horticultural and agricultural plants' yield, environmental damage and economic, social and livelihood crises in agriculture sector. Water scarcity and drought threaten food security and if no comprehensive planning be done for it, food security will be faced with many challenges.

Major indices are investigating drought based on meteorological data, specifically rainfall, and do not consider soil moisture. Maybe it can be said that the reason of no using of soil moisture in most indicators is due to the lack of direct measurements of them at the weather stations. Among the various indicators of drought, there are also indications that consider soil moisture for assessment.
The Palmer Index (PDSI) and Soil Moisture Drought Index (SMDI) are among the main drought indicators that consider soil moisture as an input parameter.
The Soil Moisture Drought Index requires limited parameters. This index is based on the daily and annual total soil moisture and soil moisture is the only climatic factor used in this index. This index is also used in annual moisture, as well (Ramazani Etedali *et al.,* 2012).
The reason of lack of using soil moisture in most of the indicators is the lack of direct measurements of them at the weather stations. Therefore, in order to determine the soil moisture over a statistical period and evaluate the agricultural drought with the help of indicators based on soil moisture, some models can be used which are based on the relationship between water and soil. The models which investigate the relations of soil, water and vegetation are used for various purposes.
These models can simulate the water flow in soil, crop growth simulation, estimating the dry material and yield, estimating soil moisture in various tissues and various depth of root development, planning irrigation etc., with regard to the weather and climatic data.
Another application of the models based on soil and water relations, is using them as a tool for system management decision making (Steduto *et al.,* 2009). This model is one of the most widely known models in the world that the main reason is its need to less data and its simplicity.
Sinclair and Seligman (1996) point out that simple models compared to complex models are superior, especially when the research purpose is very specific or related to a single component, such as water usage. By using this model, it is possible to simulate soil moisture over daily, monthly or yearly periods and based on its results, develop the index of soil moisture and evaluate agricultural drought based on the soil moisture index.
In general, the main objective of this research can be explained as simulation of soil moisture using the Aqua Crop model, using its results to calculate the soil moisture index or SMDI and finally simulation of soil moisture through the standardized precipitation index and the drought identification index.

***Research Geographical District***

Zarghan City is located at 52° 44´ and latitude 29 °46´and at an altitude 1600 meters above sea level. The weather station of Zarghan is located at 25 km northeast of Shiraz City in Southern Iran. Its altitude is 1596 meters above sea level.

## MATERIALS AND METHODS

The measured meteorological data of daily rainfall, maximum and minimum temperature, relative humidity, average wind speed and sunshine hours, were used during the period 1992 to 2012 at the agriculture reference station of Zarghan. To achieve soil data in the study area, the texture map and studies that have been done in this area, were used. The study of soil texture maps showed that the region's soil is Silty Clay.

***Calculate Potential Evapotranspiration***

The Meteorological data was imported to ET0 model and base on FAO Penman –Monteith equation, the daily potential evapotranspiration was calculated during the period 1992 to 2012.
Using the basic equation of Penman- Monteith equation and the aerodynamic resistance equation and the surface resistance, the reference evapotranspiration is estimated by the FAO Penman- Monteith method, as follows.

***Estimation of Changes In Soil Moisture At Different Soil Depths***

After calculating potential evapotranspiration, the daily necessary data including the amount of potential evapotranspiration, soil texture, soil depth profile and the simulation period were imported to the AquaCrop model. Also it was assumed that the soil surface is without vegetation (fallow).

Then, using the soil moisture index (SMDI) the agricultural drought assessment was conducted. This index is based on the total daily moisture during a year and the soil moisture is the only climatic factor used in this index (Narasimhan and Srinivasan, 2005; Ramezani Etedali *et al.*, 2012).

$$\text{if } SW_i \leq MSW_i \qquad SD_i = \frac{SW_i - MSW_i}{MSW_i - \min SW_i} \times 100 \tag{1}$$

$$\text{if } SW_i > MSW_i \qquad SD_i = \frac{SW_i - MSW_i}{MaxSW_i - MSW_i} \times 100 \tag{2}$$

i: the considered year, SW: total daily moisture during the year, MSW: the median of total daily moisture during the period, Min SW: the minimum of total soil moisture during the period, MaxSW: the Maximum of total amount of moisture during the period and SD is the lack of soil moisture. SD ranges from 100 to -100. In 100, soil is in most humid status and in – 100, soil is in driest status. Finally, the SMDI index is calculated through the equation (3).

$$SMDI_i = 0.5SMDI_{i-1} + \frac{SD_i}{50} \tag{3}$$

SMDI: soil moisture drought index. This index varies from 4 to -4 namely, from wet to dry. In this index, the previous time step is taken into account for the current drought conditions.

***Calculation of Meteorological Indices***

*The Standardized Precipitation Index (Spi)*

The standardized Precipitation Index (SPI) is one of the indices that were presented for drought monitoring. It is calculated in short-term (3, 6 and 9 months) and long-term (12, 24 and 48 months) (McKee *et al.*, 1993) periods. In any time scale, the SPI mean may reach zero in a location and its variance become equal to 1.Using the SPI, quantitative definition of drought can be established for each time scale.

A drought event for time scale i is defined here as a period in which the SPI is continuously negative and the SPI reaches a value of -1.0 or less. The drought begins when the SPI first falls below zero and ends with the positive value (Mckee *et al.*, 1993).

*The Reconnaissance Drought Index (Rdi)*

The Reconnaissance Drought Index (RDI) is calculated in three stages: Initial value of RDI ($a_0$), normalized RDI (RDIn) and standardized RDI (RDIst). Initial value may be calculated for each month, seasons (3-month, 4-month, etc.) or hydrological year. The $a_0$ is calculated by using the following equation (Tsakiris *et al.*, 2007; Asadi Zarch *et al.*, 2011).

$$a_0^{(i)} = \frac{\sum_{j=1}^{12} P_{ij}}{\sum_{j=1}^{12} PET_{ij}}, i = 1(1)N \quad and \ j = 1(1)12 \tag{4}$$

Where $P^{ij}$ and $PET^{ij}$ are the precipitation and potential evapotranspiration of the jth month of the $i^{th}$ hydrological year. N is the total number of years of the available data.

A second step, the Normalized RDI ( $RDI_n$ ) is computed using the following equation for each year, in which it is evident that the parameter $a_0$ is the arithmetic mean of $a_0$ values (Tsakiris *et al.*, 2007; Asadi Zarch *et al.*, 2011).

$$RDI_n^{(i)} = \frac{a_0^{(i)}}{\bar{a}} - 1 \quad (5)$$

The third step, the Standardized RDI ( $RDI_s$ ), is computed following a similar procedure to the one that is used for the calculation of the SPI: The equation for the Standardized RDI is:

$$RDI_{st(k)}^{(i)} = \frac{y_k^{(i)} - \bar{y}_k}{\hat{\sigma}_{yk}} \quad (6)$$

Where $y_k$ is the ln( $a_0$ ; $\bar{y}_k$ ) is its arithmetic mean of $y_k$, and $\hat{\sigma}_{yk}$ is its standard deviation.

Along the various indices for meteorological drought monitoring, SPI and RDI indices were widely accepted and used (Hayes and Svoboda, 1999; Tsakiris and Vangelis, 2004; Shamsnia and Pirmoradian, 2009; Shamsnia, 2014). Then the appropriate and common indicators such as Standardized Precipitation Index and Reconnaissance Drought Index that mostly has been confirmed in research were calculated at the same statistical period and the results of indicators were evaluated.

## RESULTS AND DISCUSSION

The rainfall height and evapotranspiration during the under studied statistical years, are shown in Figure (1). Then the volumetric percentage of soil moisture were calculated at depths of 5, 15, 2,35,45,55,65,75, 85 and 95 cm. the soil moisture percentage at depths of 5, 15, 45 and 95 cm, have been shown in Figure 4-2.Monthly changes in soil moisture is very severe at depth of 5 to 15 cm. These moisture changes mainly vary from about 10% to 32%, in different months (from permanent wilting point to agricultural capacity). The reason of the change in soil moisture in shallow layers is quite logical. The soil surface layer is more susceptible to evapotranspiration due to direct sunlight and also rainfall (even low levels) will increase soil moisture. But as in Figure (2) is determined, change in soil moisture at lower depths is negligible.

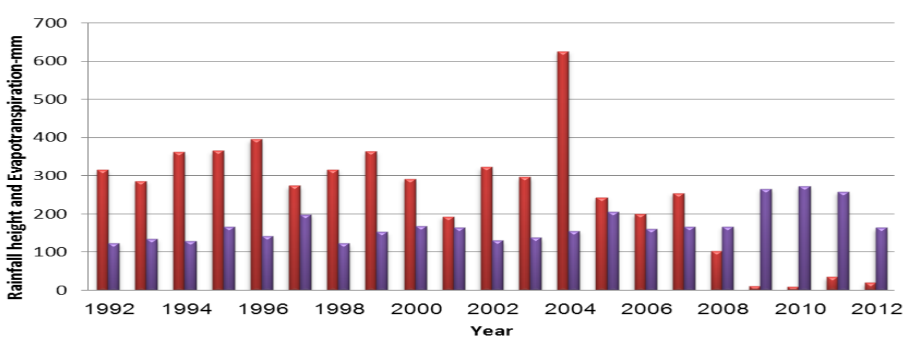


**Figure 1: Monthly changes in Rainfall and Evapotranspiration during different years**

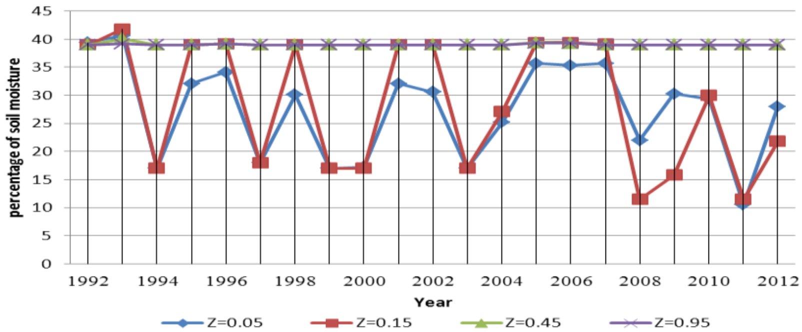


**Figure 2: Soil moisture changes over the period 1992 to 2012 at depths of 5, 15, 45 and 95 cm**

**Table 1: Values of soil moisture deficit (SD) and soil moisture deficit index (SMDI) at depths of 5 and 15 cm during 1992 to 2012**

| | Depths of 5 cm | | Depths of 15 cm | |
|---|---|---|---|---|
| **Year** | **Soil Moisture Deficit (SD)** | **Soil Moisture Deficit Index (SMDI)** | **Soil Moisture Deficit (SD)** | **Soil Moisture Deficit Index (SMDI)** |
| 1992 | 17.97 | 0.36 | 31.44 | 0.63 |
| 1993 | -4.58 | 0.09 | 2.82 | 0.37 |
| 1994 | 66.71 | 1.38 | -3.35 | 0.12 |
| 1995 | 100.00 | 2.69 | 100.00 | 2.06 |
| 1996 | 45.72 | 2.26 | 20.59 | 1.44 |
| 1997 | 25.16 | 1.63 | -34.12 | 0.04 |
| 1998 | -2.66 | 0.76 | 23.54 | 0.49 |
| 1999 | -22.84 | -0.08 | -29.14 | -0.34 |
| 2000 | 10.05 | 0.16 | -18.30 | -0.53 |
| 2001 | -37.16 | -0.66 | -10.44 | -0.48 |
| 2002 | -16.87 | -0.67 | 0.00 | -0.24 |
| 2003 | 0.00 | -0.33 | -11.34 | -0.35 |
| 2004 | -11.70 | -0.40 | 6.38 | -0.05 |
| 2005 | 9.41 | -0.01 | 52.78 | 1.03 |
| 2006 | -7.37 | -0.15 | 15.18 | 0.82 |
| 2007 | -9.43 | -0.27 | 16.11 | 0.73 |
| 2008 | 13.07 | 0.13 | -100.00 | -1.63 |
| 2009 | 1.90 | 0.10 | -90.22 | -2.62 |
| 2010 | -100.00 | -1.95 | -48.97 | -2.29 |
| 2011 | -2.22 | -1.02 | -46.84 | -2.08 |
| 2012 | 63.40 | 0.76 | 42.60 | -0.19 |

After determining the moisture content of the soil at various depths, the SMDI index was calculated. To calculate this indicator, first, the percentage of soil moisture deficit (SD) was calculated.
The results of calculating the SD and SMDI at various depths have been shown in the table (1 and 2).

**Table 2: Values of soil moisture deficit (SD) and soil moisture deficit index (SMDI) at depths of 45 and 95 cm during 1992 to 2012**

| | Depths of 45 cm | | Depths of 95 cm | |
|---|---|---|---|---|
| Year | Soil Moisture Deficit (SD) | Soil Moisture Deficit Index (SMDI) | Soil Moisture Deficit (SD) | Soil Moisture Deficit Index (SMDI) |
| 1992 | 40.21 | 0.80 | 64 | 1.28 |
| 1993 | 27.12 | 0.94 | 23.23 | 1.10 |
| 1994 | -20.49 | 0.06 | 0 | 0.55 |
| 1995 | 15.92 | 0.35 | 15.54 | 0.59 |
| 1996 | 65.34 | 1.48 | 79.54 | 1.88 |
| 1997 | -92.58 | -1.11 | -90.53 | -0.87 |
| 1998 | 13.09 | -0.29 | -0.11 | -0.44 |
| 1999 | 18.12 | 0.22 | -0.13 | -0.22 |
| 2000 | 32.88 | 0.77 | 59.38 | 1.08 |
| 2001 | -69.26 | -1.00 | -60.00 | -0.66 |
| 2002 | 0.00 | -0.50 | 0.00 | -0.33 |
| 2003 | -62.19 | -1.49 | -49.47 | -1.15 |
| 2004 | 100.00 | 1.25 | 100.00 | 1.42 |
| 2005 | -39.93 | -0.17 | -23.16 | 0.25 |
| 2006 | -31.45 | -0.72 | -7.37 | -0.02 |
| 2007 | -50.53 | -1.37 | -34.74 | -0.71 |
| 2008 | 11.20 | -0.46 | 45.38 | 0.55 |
| 2009 | -100.00 | -2.23 | -100.00 | -1.72 |
| 2010 | -100.00 | -3.11 | -100.00 | -2.86 |
| 2011 | -99.80 | -3.55 | -99.93 | -3.43 |
| 2012 | 34.03 | -1.10 | 59.54 | -0.52 |

In order to investigate the results of the index, the results of two indices, SPI, and RDI, which are calculated on the basis of meteorological parameters, has also been compared. Since the SMDI index is calculated on an annual basis, therefore, the results of SPI and RDI indices have been provided on an annual basis.
The results of the monitoring of drought by using the SMDI index at 95 cm depth, and SPI, and RDI indices and amounts of rainfall and evapotranspiration have been shown in Table 3.

**Table 3. The amount of rainfall, potential evapotranspiration, SD and SMDI index at depth of 95 cm and the SPI and RDI indices during 1992 to 2012**

| Year | Rainfall (mm) | ET0 (mm/year) | SD depth of 95 cm | SDMI depth of 95 cm | SPI Index | RDI Index |
|---|---|---|---|---|---|---|
| 1992 | 315 | 124 | 64 | 1.28 | 0.42 | 0.66 |
| 1993 | 286 | 135 | 23.23 | 1.10 | 0.23 | 0.53 |
| 1994 | 362 | 128 | 0.00 | 0.55 | 0.73 | 0.73 |
| 1995 | 366 | 166 | 15.54 | 0.59 | 0.75 | 0.56 |
| 1996 | 395 | 142 | 79.54 | 1.88 | 0.94 | 0.72 |
| 1997 | 274 | 198 | -90.53 | -0.87 | 0.15 | 0.22 |
| 1998 | 316 | 123 | -0.11 | -0.44 | 0.42 | 0.66 |
| 1999 | 364 | 153 | -0.13 | -0.22 | 0.74 | 0.61 |
| 2000 | 292 | 168 | 59.38 | 1.08 | 0.27 | 0.39 |
| 2001 | 193 | 164 | -60.00 | -0.66 | -0.39 | -0.31 |
| 2002 | 323 | 130 | 0.00 | -0.33 | 0.47 | 0.64 |
| 2003 | 296 | 138 | -49.47 | -1.15 | 0.29 | 0.54 |
| 2004 | 626 | 155 | 100.00 | 1.42 | 2.46 | 0.99 |
| 2005 | 243 | 206 | -23.16 | 0.25 | -0.06 | 0.11 |
| 2006 | 200 | 161 | -7.37 | -0.02 | -0.34 | 0.15 |
| 2007 | 254 | 166 | -34.74 | -0.71 | 0.02 | 0.30 |
| 2008 | 102 | 167 | 45.38 | 0.55 | -0.98 | -0.36 |
| 2009 | 11 | 266 | -100.00 | -1.72 | -1.58 | -2.27 |
| 2010 | 10 | 272 | -100.00 | -2.86 | -1.59 | -2.35 |
| 2011 | 35 | 258 | -99.93 | -3.43 | -1.42 | -1.43 |
| 2012 | 20 | 164 | 59.54 | -0.52 | -1.52 | -1.50 |

Comparing the results of three studied indices is shown in the figures (3 to 5). Investigating the trends of change in drought indices shows that all charts predict increased intensity of droughts in the region. In other words, the amount of rainfall in the region has been declining and the risk of drought in the region is increasing. This issue should be considered in this region as one of the poles of agriculture. All indices show that since 2005, the region has not had wet condition and has suffered from drought and its intensity has been steadily rising. In 2010 and 2011, the most severe droughts occurred that in this case, all three criteria show similar results.

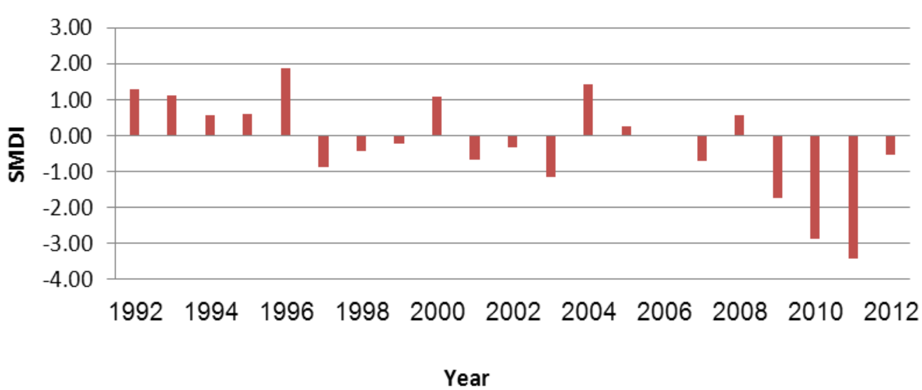


**Figure 3: Drought monitoring using soil moisture deficit index (SMDI) at Zarghan station**

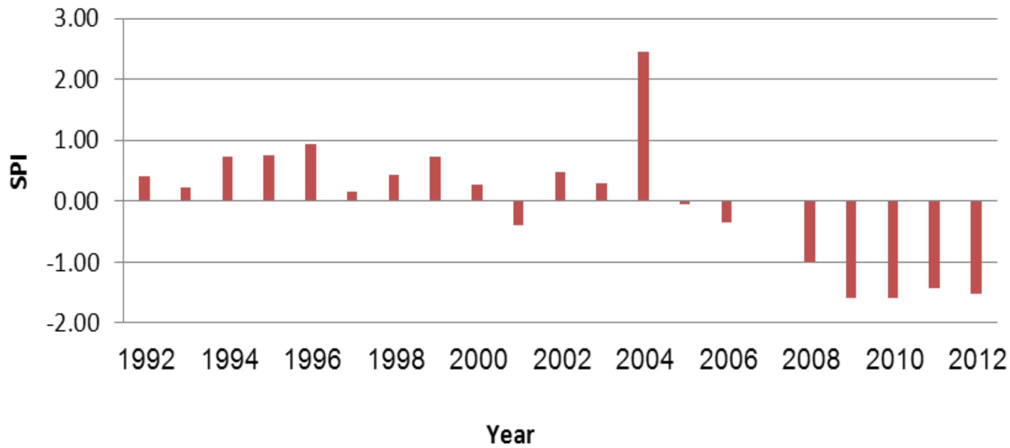


**Figure 4: Drought monitoring using the standardized precipitation index (SPI) at Zarghan station**

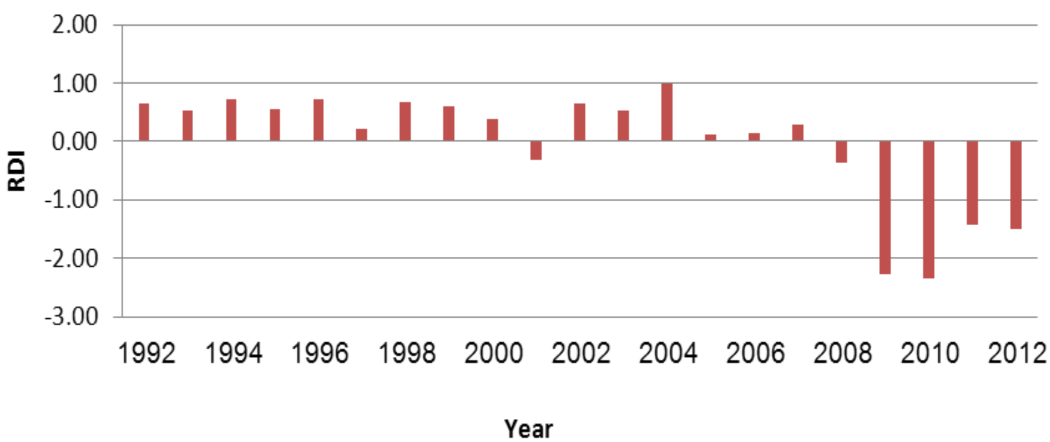


**Figure 5: Drought monitoring using the reconnaissance drought index (RDI) at Zarghan station**

Then the relationships between indicators of drought, rainfall and evapotranspiration were investigated and the correlation coefficients of parameters were determined. The correlation results are shown in Table (4). This issue has been the same in the studies of Narasimhan and Srinivasan (2005) and Ramezani Etedali *et al.*, (2012). The most correlation of evapotranspiration is related to the RDI index due to the nature and the calculation of the RDI index. In calculating the index, two parameters of potential evapotranspiration and rainfall are effective.

**Table 4: The correlation matrix between meteorological parameters and studied drought indices**

| | **Rainfall** | **ET0** | **SD** | **SMDI** | **SPI** | **RDI** |
|---|---|---|---|---|---|---|
| Rainfall | 1 | 0.447 | 0.326 | 0.49 | 1 | 0.792 |
| ET0 | | 1 | 0.464 | 0.531 | 0.447 | 0.713 |
| SD | | | 1 | 0.752 | 0.326 | 0.319 |
| SMDI | | | | 1 | 0.49 | 0.545 |
| SPI | | | | | 1 | 0.792 |
| RDI | | | | | | 1 |

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